Indian J. Phys. **74B** (6), 497–499 (2000)

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I J P B
an international journal

On the effect of ionized plasma medium on the resonant frequencies of microstrip patch antennas

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Received 29 October 1999, accepted 16 October 2000

Abstract : An analysis has been made to study the effect of ionized (plasma) medium on the resonant frequencies of three different types of patch antennas *viz.* rectangular patch antenna, square patch antenna and circular patch antenna. The technique which calculates the resonant frequency of a microstrip patch antenna takes into account the effect of permittivity on the surrounding plasma medium. The present analysis reveals that the resonant frequency is enhanced by a marked difference on the effect of plasma medium in comparison to free space medium.

Keywords : Resonant frequency, microstrip patch antenna, plasma medium

PACS Nos. : 84.40.Ba, 52.40.Fd

In the recent years, microstrip antennas have attracted a lot of researchers due to their unique advantages such as low cost, light weight, flat profile, conformity to surface and direct integratability with microwave circuitry [1–4]. Due to these advantages, these antennas are found to be more suitable to be used on aerospace vehicles and satellites. Antennas mounted on such aerospace vehicles encounter plasma medium during their travel in space, as a result of which electroacoustic waves are also generated with usual electromagnetic waves [5,6]. This gives rise to detuning of antenna to a great extent which affects the performance of microstrip antenna very much due to narrow bandwidth [3,7]. The effect is very much pronounced upto X-band of microwave frequency which finds more applications day by day. Thus, it is necessary to study the resonant frequency of microstrip antenna exactly as it operates efficiently only near its resonant frequency. In the earlier studies of microstrip antennas in plasma medium [5–9], the effective permittivity of the antenna that affects the resonant frequency of antenna has been calculated for free space. This gives erroneous results when the antenna is actually surrounded by a plasma medium.

In the present study, we have performed an analysis to compute the resonant frequencies of rectangular patch microstrip antenna (RPMA), square patch microstrip antenna (SPMA) and circular patch microstrip antenna (CPMA) in plasma medium. The reason behind choosing these geometries is that they are commonly employed microstrip radiating elements.

The configurations and coordinate systems of two different microstrip geometries *viz* RPMA and CPMA are depicted in Figure 1.

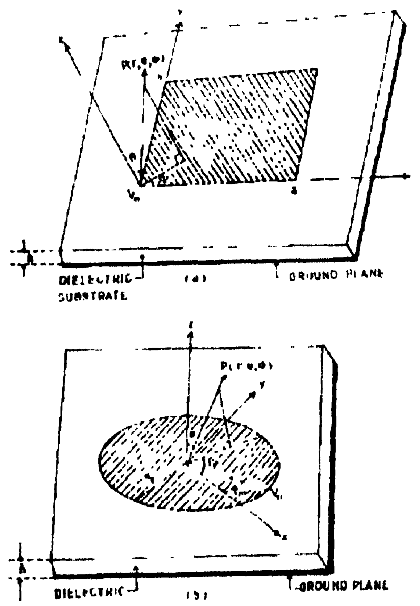

Figure 1. Configuration and coordinate system of microstrip patch antennas : (i) rectangular patch, (ii) circular patch

In Figure 1(a), a rectangular patch of size $a \times b$ on a dielectric substrate of thickness h which is backed by a ground plane is shown. Since the dimensions of the patch are small in comparison to wave length, so the region under the patch may be modelled as a thin cavity with leaking magnetic side walls [10]. Such a cavity supports quasi-discrete TM_{nm} modes. The RPMA is reduced to SPMA for $a = b$. In this case, the modes set with $m^2 + n^2$ = constant. The Figure 1(b) shows the geometry of CPMA, which consists of a thin conducting circular patch of radius a, on a dielectric substrate of thickness h. The patch can be excited by a microstrip transmission line connected to the edge or by a coaxial line from the back at the plane $\phi = \phi_m$. In both the patches, the total electric field inside the cavity can be expressed as the sum of the fields associated with each mode. The resonant frequency of RPMA (f_r') and of CPMA (f_r'') are expressed in the same manner as for cut-off in the wave guide [8,11].

$$f_r' = \frac{c}{2\sqrt{\varepsilon_{re}(f)}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \tag{1}$$

and
$$f_r'' = \frac{ck_{nm}}{2\pi a\sqrt{\varepsilon_{re}(f)}}, \tag{2}$$

where $k_{nm} = 1.84118$ (for dominant mode), c is the velocity of light and $\varepsilon_{re}(f)$ is the effective permittivity of the microstrip structure which lies between the relative permittivity of the substrate material and the relative permittivity of its surrounding medium. For the free space surrounding, it is given as [12]

$$\varepsilon_{re}(f) = \frac{1}{2}\left\{(\varepsilon_r + 1) + (\varepsilon_r - 1)\left(1 + 10\frac{h}{w}\right)^{-\frac{1}{2}}\right\}. \tag{3}$$

Here, ε_r is the relative permittivity of the substrate and w is the width of the microstrip patch.

In eq. (3), the factor 1, which has been added and substracted from ε_r in the two terms of R H.S. is the relative permittivity of the free space. But we have discussed that the actual surrounding medium is plasma, hence 1 in eq. (3) has to be replaced by ε_p, the relative permittivity of plasma. Thus, for plasma embeded microstrip antenna, the effective permittivity will be given as

$$\varepsilon_{rep} = \frac{1}{2}\left\{(\varepsilon_r + \varepsilon_p) + (\varepsilon_r - \varepsilon_p)\left(1 + 10\frac{h}{w}\right)^{-\frac{1}{2}}\right\} \tag{4}$$

Here, ε_p is expressed as

$$\varepsilon_p = 1 - \frac{\omega_p}{\omega_0} = A^2.$$

A being the plasma parameter, ω_p and ω_0 are the plasma frequency and operating frequency respectively.

For dominant mode ($m = 1$, $n = 0$) eqs. (1) and (2) will be modified including plasma effects (eq. 4) as follows :

$$f_{rp}' = \frac{c}{2a\sqrt{\varepsilon_{rep}(f)}}, \tag{5}$$

$$f_{rp}'' = \frac{1.84118c}{2\pi a\sqrt{\varepsilon_{rep}(f)}}. \tag{6}$$

The resonant frequencies of RPMA and SPMA are determined with the help of eq. (5) and of CPMA with the help of eq. (6) for the formica substrate of thickness $h = 0.16$ cm and dielectric constant $\varepsilon_r = 3.55$ at the operating frequency 10 GHz (X-band).

It is found from the above study that there is a significant change in the resonant frequencies of microstrip patch antennas due to plasma effect. As noticed from the given expressions, the resonant frequency is a function of effective permittivity and plasma frequency (ω_p). Figure 2 illustrates

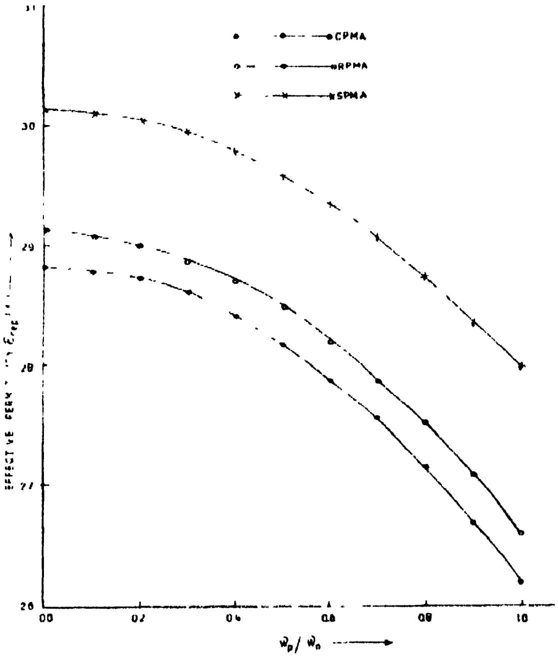

Figure 2. Variation of effective permittivity $\varepsilon_{rep}(f)$ with plasma frequency (ω_p) for rectangular, square and circular patch microstrip antennas.

the variation of effective permittivity $\varepsilon_{rep}(f)$ whereas Figure 3 depicts the variation of resonant frequency for RPMA, SPMA and CPMA with varying plasma contents (ω_p/ω_0).

In these figures, it is observed that the effective permittivity for all the three cases of patch antennas decreases with increase in plasma frequency. As a matter of fact, the resonant frequency is enhanced by a substantial amount, from the free space value (f_r' and f_r''). The increment in resonant frequency is greatest in case of CPMA and smallest in case of SPMA. It is further seen that the resonant frequency increases slowly in low frequency plasma region while it increases rapidly in high frequency plasma region.

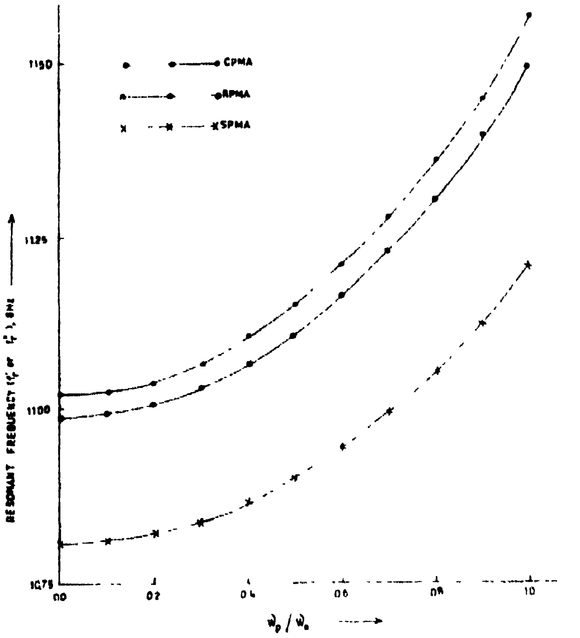

Figure 3. Variation of resonant frequencies (f_{rp} or f'_{rp}) with plasma frequency (ω_p) for rectangular, square and circular patch microstrip antennas.

Acknowledgments

The author is thankful to the Referee for his valuable comments which have been very useful in revising the manuscript. Thanks are also due to the Principal, R H Government, P G College, Kashipur for providing him the necessary facilities and constant encouragement.

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